Italian Botanist 13: 45–65 (2022)
doi: 10.3897/italianbotanist.13.81812
https://italianbotanist.pensoft.net

RESEARCH ARTICLE

Italian Botanist
Published by Società Botanica Italiana

Spring composition of the macroalgal vegetation of a small offshore island in the north-western Mediterranean (Gallinara Island, Ligurian Sea)

Fabio Rindi[1], Brigitte Gavio[2], Laura Pezzolesi[3,4], Daniela Pica[5], Massimo Ponti[3,4,6,7], Fabrizio Torsani[1], Carlo Cerrano[1,6]

1 *Dipartimento di Scienze della Vita e dell'Ambiente, Via Brecce Bianche, 60131 Ancona, Italy* **2** *Departamento de Biología, Facultad de Ciencias, Sede Bogotá, Universidad Nacional de Colombia, Bogotá, Colombia* **3** *Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Università di Bologna, Via Sant'Alberto 163, 48123 Ravenna, Italy* **4** *Centro Interdipartimentale di Ricerca Industriale Fonti Rinnovabili, Ambiente, Mare ed Energia e Centro Interdipartimentale di Ricerca per le Scienze Ambientali, Università degli studi di Bologna, Ravenna, Italy* **5** *Stazione Zoologica Anton Dohrn, C. da Torre Spaccata, località Torre Spaccata, 87071 Amendolara (CS), Italy* **6** *Reef Check Italia onlus, Ancona, Italy* **7** *Consorzio Nazionale Interuniversitario per le Scienze del Mare, Roma, Italy*

Corresponding author: Fabio Rindi (f.rindi@univpm.it)

Academic editor: Cecilia Maria Totti | Received 7 February 2022 | Accepted 29 March 2022 | Published 27 May 2022

Citation: Rindi F, Gavio B, Pezzolesi L, Pica D, Ponti M, Torsani F, Cerrano C (2022) Spring composition of the macroalgal vegetation of a small offshore island in the north-western Mediterranean (Gallinara Island, Ligurian Sea). Italian Botanist 13: 45–65. https://doi.org/10.3897/italianbotanist.13.81812

Abstract

Gallinara Island, a small island located 1.5 km off the shore of Liguria (Italy, north-western Mediterranean Sea) was included in a list of proposed Marine Protected Areas (MPA) in the early 90s. Since then, its benthic assemblages have been studied in detail and the main macrophytic communities have been mapped. A detailed assessment of its benthic macroalgal flora, however, has never been made. Gallinara was visited in the course of 5 consecutive years and its macroalgal flora was studied based on collections made by snorkelling and SCUBA diving. Overall, 141 macroalgal taxa were collected and identified (23 Chlorophyta, 94 Rhodophyta, 24 Ochrophyta); 91 of them represent new records for the island. One of the most notable new records is the non-indigenous red alga *Womersleyella setacea*, previously unreported from the island and widely distributed, particularly on the south-eastern shore. Observations made in the course of the surveys confirm the rarefaction of some large-sized brown algae (particularly *Sargassum vulgare*) but indicate also that others previously reported as rare (*Cystoseira compressa*, *Dictyopteris polypodioides*) are still common on the island.

Keywords

Biotic homogenization, Macroalgal floras, Marine Protected Areas, Mediterranean sea, non-indigenous species

Copyright *Fabio Rindi et al.* This is an open access article distributed under the terms of the Creative Commons Attribution License (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Introduction

Littoral systems around small islands often show peculiar characteristics, both biotic and abiotic, if compared with those of mainland coasts (Piazzi et al. 2004; Rindi and Guiry 2004). Differences in environmental factors such as wave exposure, currents, water transparency, sedimentation rate and interaction with pelagic systems are considered the main causes of these peculiarities (Piazzi et al. 2004). Such differences are usually more evident for islands located at greater distances from the mainland. In the last decades, anthropogenic impacts affecting many littoral habitats along continental shores have further contributed to increase these differences. This is a common situation in the north-western Mediterranean Sea, where the limited urbanization typical of many offshore islands has allowed the maintenance of a comparatively high environmental status, in contrast to the highly impacted continental shores in the region.

Gallinara is a small island located in the Ligurian Sea, approximately 1.5 km from the western shore of Liguria, in the Italian mainland. The island is not open to public access and its terrestrial biota, consisting mainly of Mediterranean shrublands, are generally well conserved, with the presence of rare and endemic species listed in Habitat Directive (e.g *Campanula sabatia* De Notaris 1844). Moreover, the island hosts one the main colonies of the seagull *Larus michahellis* Naumann 1840, of the Ligurian region. For this reason, a Natural Regional Reserve was established for the terrestrial environment in 1989 (Bianchi et al. 2018). The marine benthic communities of Gallinara were not studied in detail until the early 90s of last century (Balduzzi et al. 1992), when the island was included in a list of proposed Marine Protected Areas (MPA) in the framework of the Italian National Framework Law 394/91 on Protected Areas. To date a Marine Protected Area has not yet been established, but the island is included in a Special Area of Conservation (SAC "Fondali Santa Croce - Gallinara - Capo Lena", Natura 2000 code IT1324974). Despite of this, there is evidence that the rocky bottoms surrounding the island underwent major alterations due to increasing human impacts in the last 25 years, mainly in the form of anchoring and fishing, both artisanal and recreational (Bianchi et al. 2018).

The benthic macrophyte communities of Gallinara were characterized and mapped in several studies (Balduzzi et al. 1992; Tunesi et al. 2006, 2008; Bianchi et al. 2018) that provided a background of knowledge for the establishment of the MPA. Macrophytes (seagrasses and benthic macroalgae) are considered useful descriptors of environmental characteristics of coastal habitats (Pinedo et al. 2007; Balata et al. 2011). Attached algae, because of their sedentary condition, integrate the effects of long-term exposure to nutrients or other pollutants resulting in a decrease or even disappearance of the most sensitive species and its replacement by highly resistant, opportunistic species (Ballesteros et al. 2007). Therefore, these organisms are widely used for environmental assessments of coastal waters (Orlando-Bonaca et al. 2008; Orfanidis et al. 2011; Cecchi et al. 2014; D'Archino and Piazzi 2021) and the seaweed communities occurring in an area are an important aspect to take in account when the establishment of an MPA is considered.

Previous investigations have reported 71 species of macroalgae from Gallinara, but a detailed census of the macroalgal flora was not among their aims. In general, detailed recent studies focusing on the macroalgal diversity of the region where Gallinara is located (Liguria) are essentially lacking. We visited the island each year in a time span of 5 years (2013–2017) and made targeted collections and observations on the benthic macroalgae. This improved substantially the knowledge of the macroalgal vegetation, providing new valuable floristic information. Observations of the seaweed communities also allowed to compare the present distribution of several species with information available in the literature.

Materials and methods

Study site

Gallinara Island has a triangular outline and its perimeter measures approximately 1.4 km (Fig. 1). The coastline is entirely rocky and consists mostly of steep cliffs. With the only partial exception of the north-eastern shore where a small harbour is located, the island is characterized by wave-exposed conditions, due to exposure to southerly and south-easterly winds (that are the prevailing in the area). As in most of the Mediterranean Sea, the tidal range is limited and does not exceed 0.3 m (Bianchi et al. 2018). From the lithological point of view the island consists entirely of stratified quartzite (Bavestrello et al. 2000).

Methods

Gallinara Island was visited in June in 5 consecutive years (9–14 June 2013; 9–14 June 2014; 7–12 June 2015; 5–10 June 2016; 5–10 June 2017). Collections of benthic macroalgae were made from the mediolittoral, infralittoral and circalittoral zones, at depths ranging from the surface to approximately 45 m. Collections from the mediolittoral and shallow infralittoral (-1.5/2 m) zones were made by snorkeling along the whole shoreline of the island. Collections from the infralittoral and circalittoral zones were made from two sites, Punta Falconara (southern point of the island) and Punta Sciusciaù (eastern point of the island) by SCUBA diving. Sampling was based on targeted collections, made with the aim of collecting as many species as possible.

In addition, a visual census of the seaweed communities of the mediolittoral and shallow infralittoral zone (approximately 5 m depth) was carried out in June 2016. The whole perimeter of the island was checked by visual inspection and the species present were noted. For convenience, we present and discuss the results subdividing the island in 30 sectors of the four shores: north-eastern shore (NE, sectors 1–7), south-eastern shore (SE, sectors 8–19), western shore (W, sectors 20–29) and harbour (H, sector 30).

Algal samples were removed from the substratum using a sharp knife or hammer and chisel (except for some samples from the infralittoral zone, which were collected

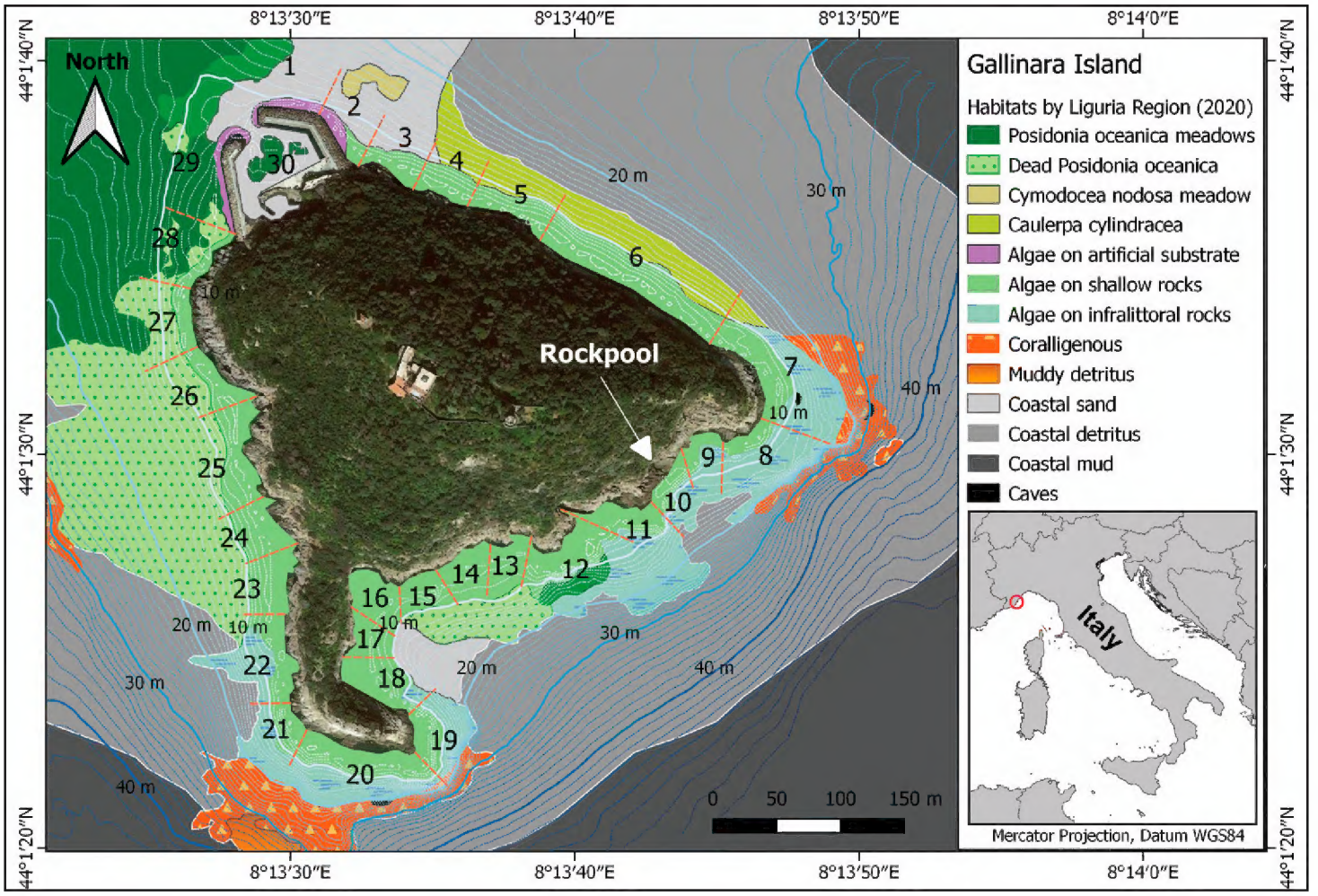

Figure 1. Map of Gallinara Island. Numbers indicate the study sectors around the island shore. Main benthic habitats are reported according to Regione Liguria (2020).

using a vacuum pump). The material was placed in sealed plastic bags and examined a few hours after collection using a binocular stereoscope and a light microscope. Part of the material was immediately identified, dried, and pressed for preparation of herbarium specimens. Some specimens that could not be readily identified were stored in a solution of 4% formalin in seawater and identified upon return to the laboratory at the Polytechnic University of Marche. Identifications were based on morphological characters and were obtained using descriptions and illustrations mainly in Coppejans (1983), Cormaci et al. (2012, 2014, 2017, 2020, 2021) and Rodriguez-Prieto et al. (2013). Voucher specimens were deposited in the herbarium JIWUKORI of the Universidad Nacional de Colombia, Bogotá (JIW) and in the phycological section of the Herbarium Anconitanum, Università Politecnica delle Marche, Ancona (ANC). Algal nomenclature and taxonomy follow AlgaeBase (Guiry and Guiry 2022).

Results

Overall, 141 macroalgal taxa were collected and identified in the study (23 Chlorophyta, 94 Rhodophyta, 24 Ochrophyta) (Table 1); 91 of these represent new records for the island (Table S1). In terms of distribution, 11 taxa were recorded from the harbour, 65 from the NE shore, 126 from the SE shore and 88 from the W shore (Table 1).

Table 1. List of macroalgal taxa collected and identified from Gallinara Island. Labels: H = harbour; NE = northeastern shore; SE = southeastern shore; W = western shore. Crosses indicate presence.

Phylum and taxon	Sector				Distributional notes
	H	NE	SE	W	
Chlorophyta					
Acetabularia acetabulum (Linnaeus) P.C. Silva		+	+	+	Widespread in the shallow part of the infralittoral zone (-1/5 m), particularly on the NE shore.
Anadyomene stellata (Wulfen) C. Agardh			+		Collected in 2017; some small thalli mixed with filamentous algae in the shallow infralittoral.
Bryopsis cf. *duplex* De Notaris		+	+	+	Some specimens mixed with filamentous algae in the photophilous turfs of the infralittoral fringe.
Bryopsis sp.			+		A few specimens with fir-like habit; collected in 2017.
Caulerpa cylindracea Sonder			+		In the infralittoral zone, with a wide depth range; more abundant around 10 m than at higher depths. Found also in the rockpool with *Cystoseira* and *Sargassum*, with a few filaments scattered in the underlayer.
Chaetomorpha aerea (Dillwyn) Kützing		+	+	+	Uncommon, mixed with other filamentous algae in mesolittoral turfs.
Chaetomorpha ligustica (Kützing) Kützing		+	+	+	Filaments mixed with other filamentous algae in both photophilous and sciophilous turfs of the mesolittoral and the infralittoral fringe. Particularly common in 2017, when it formed monospecific tufts in the lower mesolittoral.
Cladophora coelothrix Kützing			+	+	Some specimens mixed with other filamentous algae in the sciophilous turfs of the W shore; some plants collected also at Sciusciaù at 7/8 m depth.
Cladophora cf. *dalmatica* Kützing		+	+	+	Not frequent; some plants forming green tufts in the lower mesolittoral, especially in the sectors 2 and 3.
Cladophora pellucida (Hudson) Kützing			+		Collected in 2015.
Cladophora prolifera (Roth) Kützing			+		Collected in a vacuum pump sample taken at Sciusciaù at 20 m depth in 2014; found mixed with other filamentous algae in the infralittoral in 2017. Probably common in the infralittoral.
Codium bursa (Linnaeus) C. Agardh		+	+	+	Common in the infralittoral along the whole coastal perimeter. Particularly abundant in 2017.
Codium coralloides (Kützing) P.C. Silva	+				Collected in shaded crevices in the harbour in 2017.
Codium effusum (Rafinesque) Delle Chiaje				+	It formed an extended and continuous coverage on some small vertical walls in shaded crevices in the sectors 28–29.
Codium vermilara (Olivi) Delle Chiaje				+	Upper infralittoral; present mostly along the coast on the W side of the harbour.
Flabellia petiolata (Turra) Nizamuddin				+	In the upper infralittoral it is present only in shaded crevices on vertical walls of the west side. Found also in shaded crevices in the harbour in 2017.
Halimeda tuna (J. Ellis & Solander) J.V. Lamouroux	+	+	+	+	Abundant, common at all levels in the infralittoral. In the upper infralittoral it is present in some shaded crevices in the harbour and on vertical walls of the W shore.
Pedobesia simplex (Meneghini ex Kützing) M.J. Wynne & Leliaert	+				On the sandy bottom of the sheltered zone of the harbour (44°1'36.31"N, 8°13'29.56"E); several unattached thalli that form 4–5 cm wide tufts, free on the bottom.
Pseudobryopsis myura (J. Agardh) Berthold			+		Uncommon, mixed with filamentous red algae in the sciophilous turfs on the south-eastern side (sectors 15–16).
Pseudochlorodesmis furcellata (Zanardini) Børgesen		+	+	+	Widely distributed in the infralittoral, also present in the sciophilous turfs of the sectors 15–16 and 27–28. Found in the harbour in 2017, where it formed small epiphytic pompons on larger algae.
Ulva cf. *flexuosa* Wulfen		+	+	+	Not frequent, occasionally mixed with other algae in the photophilous turfs of the lower mesolittoral and the infralittoral fringe.
Ulva cf. *laetevirens* Areschoug			+		Laminar forms of *Ulva* were not observed in the mesolittoral and the upper infralittoral. A dense patch was observed in the rockpool of the sector 11 in 2014, in the only portion of the substratum not occupied by *Cystoseira* and *Sargassum*.
Valonia utricularis (Roth) C. Agardh				+	Mixed with other algae in both photophilous and sciophilous turfs of the mesolittoral and the infralittoral fringe; it forms small clusters in shaded crevices of the sectors 28–29. Epiphyte on *Stypocaulon scoparium* at 25/30 m depth at Sciusciaù.
Rhodophyta					
Acrosorium ciliolatum (Harvey) Kylin			+	+	Common in the filamentous turfs of sciophilous habitats, especially in the sectors 15–16 and 27–28. Present also in the underlayer of the rockpool of the sector 11 with *Cystoseira* and *Sargassum*.
Cf. *Acrosymphyton purpuriferum* (J. Agardh) Sjöstedt		+	+	+	Small specimens (2–3 cm tall) occasionally observed in the upper infralittoral (sectors 6, 7, 8, 9 and 21). Found also in the rockpool of the sector 11 with *Cystoseira* and *Sargassum* in 2017.

Phylum and taxon	Sector				Distributional notes
	H	NE	SE	W	
Acrothamnion preissii (Sonder) Wollaston			+		Infralittoral, observed in a single sample (epiphyte on the stipe of *Stypocaulon scoparium* at 7/8 m depth at Sciusciaù in 2014).
Aglaothamnion caudatum (J. Agardh) Feldmann-Mazoyer			+		Recorded in 2015 in sciophilous turfs.
Amphiroa rigida J.V. Lamouroux		+	+	+	Specimens observed in the upper infralittoral in the sectors 6, 7, 10, 13, 14, 16, 17, and 21. Sometimes mixed with filamentous species in the photophilous red algae turfs.
Antithamnion cruciatum (C. Agardh) Nägeli			+		Uncommon, recorded in some samples collected from vertical walls on the SE shore, mixed with other filamentous red algae.
Aphanocladia stichidiosa (Funk) Ardré			+	+	Common in the sciophilous turfs collected in the sectors 14–15 and 28–29.
Asparagopsis sp. (sporophyte *Falkenbergia*)		+	+	+	Common in the upper infralittoral of the whole island; particularly abundant in the sectors 13 and 14. When well developed, it forms pink tufts that were observed in all areas; often mixed with others filamentous algae in the turfs of the infralittoral fringe.
Bonnemaisonia asparagoides (Woodward) C. Agardh			+		Collected in the deep infralittoral in 2016 and in the rockpool with *Cystoseira* and *Sargassum* in 2017.
Botryocladia botryoides (Wulfen) Feldmann			+		Deep infralittoral, collected in 2017.
Cf. *Callithamnion corymbosum* (J.E. Smith) Lyngbye				+	Rare, mixed with other filamentous algae in the sciophilous turfs collected on the western side.
Callithamnion granulatum (Ducluzeau) C. Agardh		+	+	+	Common in the mesolittoral; more frequent in the sectors 9–13, where it formed 5–6 cm long tufts.
Carradoriella elongata (Hudson) Savoie & G.W. Saunders			+		Found in a single sample collected at 20 m depth in 2014.
Centroceras clavulatum (C. Agardh) Montagne		+	+	+	Not abundant, but widely distributed in the infralittoral; present in the sciophilous turfs collected in the upper infralittoral on the western side, in a collection made at 7–8 m depth at Sciusciaù and in vacuum pump samples taken at 20 m depth at Sciusciaù.
Ceramium ciliatum (J. Ellis) Ducluzeau		+	+	+	It is one of the most common algae in the mesolittoral and in the infralittoral fringe; in some spots it forms a continuous belt in the lower mesolittoral.
Ceramium codii (H. Richards) Feldmann-Mazoyer			+	+	Not abundant, but present at all levels of the infralittoral as epiphyte on larger algae.
Ceramium diaphanum (Lightfoot) Roth		+	+	+	Not abundant, but widely distributed in the infralittoral, mixed with other filamentous algae in the sciophilous turfs, found at 7–8 m depth at Sciusciaù and collected in the vacuum pump sample taken at 10 m depth at Falconara in 2014.
Ceramium siliquosum (Kützing) Maggs & Hommersand		+	+	+	Present in the infralittoral fringe, usually mixed with other filamentous algae in turfs.
Ceramium tenerrimum (G. Martens) Okamura		+	+	+	Present in the infralittoral fringe, usually mixed with other filamentous algae in turfs.
Ceramium virgatum Roth		+	+	+	Common in the lower mesolittoral and in the infralittoral fringe, usually mixed with other filamentous algae in turfs.
Champia parvula (C. Agardh) Harvey			+	+	Widely distributed in the infralittoral; found in the sciophilous turfs of the sectors 14–15 and 28–29, in turfs on the north-eastern side and in the vacuum pump sample taken at 20 m depth at Sciusciaù in 2014.
Chondria boryana (De Notaris) De Toni		+	+	+	Common in the lower mesolittoral and in the infralittoral fringe, especially on the south-eastern side.
Chondria capillaris (Hudson) M.J. Wynne				+	Some plants found in the sciophilous turfs collected on the west side.
Chondria cf. *mairei* Feldmann-Mazoyer			+		Collected in 2015, mixed with filamentous algae in the infralittoral.
Contarinia squamariae (Meneghini) Denizot				+	Epiphytic on some plants of *Peyssonnelia squamaria* collected in the sectors 27 and 28 in 2014.
Corallina officinalis Linnaeus		+	+	+	Uncommon, but observed on all sides of the island. It forms patches in some sheltered and partially shaded crevices.
Crouania attenuata (C. Agardh) J. Agardh			+	+	Small epiphyte present at all levels of the infralittoral. Present in the sciophilous turfs at 7/8 m depth at Sciusciaù, in the vacuum pump sample taken at 10 m depth at Falconara in 2014, and epiphyte on *Pterocladiella capillacea* in a shaded crevice in the sector 28.
Cryptonemia palmetta (S.G. Gmelin) Woelkerling, G. Furnari, Cormaci & J. McNeill			+		Some small thalli collected in the deep infralittoral mixed with filamentous algae.
Dasya ocellata (Grateloup) Harvey		+	+	+	Not abundant, but frequently observed in the photophilous turfs mixed with other filamentous algae.
Dasya rigidula (Kützing) Ardissone		+	+	+	Not abundant, but frequently observed in the photophilous turfs mixed with other filamentous algae.

Phylum and taxon	Sector				Distributional notes
	H	NE	SE	W	
Ellisolandia elongata (J. Ellis & Solander) Hind & Saunders		+	+	+	Very common in the upper infralittoral. Sometimes it forms more or less pure patches, but more often is mixed with filamentous (*Herposiphonia*, *Ceramium*, *Vertebrata*, *Polysiphonia*) and corticate (*Laurencia obtusa*) algae in turfs.
Erythrocystis montagnei (Derbès & Solier) P.C. Silva		+	+	+	Very common, parasite in the apical cavities of *Laurencia obtusa*.
Erythroglossum sandrianum (Kützing) Kylin			+		Found on a bryozoan collected at 30 m depth in 2017.
Erythrotrichia carnea (Dillwyn) J. Agardh		+	+	+	Small epiphyte observed on many larger seaweeds, probably common.
Eupogodon planus (C. Agardh) Kützing			+		Deep infralittoral, collected in 2017 mixed with other filamentous algae.
Feldmannophycus rayssiae (Feldmann & Feldmann-Mazoyer) Augier & Boudouresque			+	+	Occasionally mixed with filamentous algae in both sciophilous and photophilous turfs of the infralittoral fringe.
Gastroclonium clavatum (Roth) Ardissone		+	+	+	Small individuals (2–3 cm high) recognizable by the whitish iridescence. Frequent in the mesolittoral and in the infralittoral fringe, especially in the sectors 10–14 on the south-eastern side.
Gayliella mazoyerae Cho, Fredericq & Hommersand		+	+	+	Very common, epiphyte on larger algae in all levels of the infralittoral; observed in large quantities on *Codium effusum* and *Dictyota* spp.
Gelidium cf. *crinale* (Turner) Gaillon			+		Observed occasionally in the photophilous turfs of the infralittoral on the south-eastern side, mixed with filamentous algae.
Grateloupia filicina (J.V. Lamouroux) C. Agardh)		+			Rare; found in one mesolittoral turf collected on the north-eastern side in 2017.
Griffithsia phyllamphora J. Agardh			+	+	One of the most common species in the sciophilous turfs of the sectors 14–15 and 28–29; sometimes it forms small spherical aggregates around the axes of articulated corallinaceae or other algae. Collected in shaded crevices of the harbour in 2017.
Halopithys incurva (Hudson) Batters			+		Collected in the rockpool with *Cystoseira* and *Sargassum* in 2017.
Herposiphonia secunda (C. Agardh) Ambronn		+	+	+	Abundant; it is one of the most common species in the photophilous turfs of the infralittoral fringe. Present as epiphyte also at the deeper levels of the infralittoral.
Herposiphonia tenella (C. Agardh) Ambronn			+	+	Very common species in the sciophilous turfs of the sectors 14–15 and 28–29; sometimes it forms dense tufts almost monospecific.
Heterosiphonia crispella (C. Agardh) M.J. Wynne			+	+	Common in the sciophilous turfs collected in the sectors 14–15 and 28–29.
Hydroliython farinosum (J.V. Lamouroux) Penrose & Y.M. Chamberlain		+	+	+	Common as epiphyte on larger algae in the infralittoral.
Hydroliython farinosum var. *chalycodictyum* (W.R. Taylor) Serio			+		Deep infralittoral, found growing on a sponge.
Hypnea musciformis (Wulfen) J.V. Lamouroux		+	+	+	Epiphytic on *Cystoseira* in the rockpool with *Cystoseira* and *Sargassum*. Occasionally observed in the infralittoral fringe.
Hypoglossum hypoglossoides (Stackhouse) Collins & Hervey			+	+	Common in the sciophilous turfs collected in the sectors 14–15 and 28–29.
Jania rubens (Linnaeus) J.V. Lamouroux		+	+	+	Widespread at all levels in the infralittoral; sometimes abundant, but it never forms a belt.
Jania virgata (Zanardini) Montagne		+	+	+	Very common, epiphyte on larger algae. Widely spread at all levels of the infralittoral, but it never forms a belt.
Laurencia cf. *majuscula* (Harvey) Lucas			+		Collected in the infralittoral in 2017.
Laurencia obtusa (Hudson) J.V. Lamouroux		+	+	+	It is the most common and abundant alga in the upper infralittoral. Present mainly in form of erect thalli 4–5 cm high, but it is also common in the algal turfs in form of prostrate axes mixed with filamentous algae and articulated corallines.
Liagora cf. *viscida* (Forsskål) C. Agardh	+		+	+	Not frequent; isolated specimens observed in the sectors 13, 21–22 and 30.
Lithophyllum byssoides (Lamarck) Foslie		+	+	+	Present on almost the entire coastal perimeter in form of small isolated specimens (no more than 5 cm in diameter). A well-developed trottoir was not observed in any area.
Lithophyllum cf. *incrustans* Philippi		+	+	+	It forms patches in the upper infralittoral, in the part of substrate free from turfs or other algae.
Lithophyllum pseudoracemus Caragnano, Rodondi & Rindi			+		It forms rhodoliths at 40 m depth in the area of Punta Falconara.
Lithophyllum stictiforme (Areschoug) Hauck			+		Common in the deep infralittoral and circalittoral.
Lophosiphonia cristata Falkenberg		+	+	+	Common in the turfs of the infralittoral fringe, associated with *Polysiphonia opaca* and *Taenioma nanum*.
Nemalion elminthoides (Velley) Batters		+	+	+	Occasionally observed in the mesolittoral in form of isolated specimens (sectors 3 and 20). Unusually abundant and particularly developed in 2016.

Phylum and taxon	Sector				Distributional notes
	H	NE	SE	W	
Osmundea sp.			+		Mixed with filamentous algae in the photophilous turfs on the south-eastern side.
Peyssonnelia cf. *heteromorpha* (Zanardini) Athanasiadis	+				On stones in shaded crevices in the harbour in 2017.
Peyssonnelia cf. *rosa-marina* Boudouresque & Denizot			+		Collected at 10 m depth at Sciusciaù, probably common in the infralittoral and circalittoral.
Peyssonnelia rubra (Greville) J. Agardh			+		Common in the infralittoral, collected at 10 m depth at Sciusciaù.
Peyssonnelia squamaria (S.G. Gmelin) Decaisne	+	+			Common in some superficial shaded crevices on the western side and in the harbour.
Plocamium cf. *cartilagineum* (Linnaeus) P.S. Dixon	+		+	+	Sciophilous species present in shaded and sheltered crevices. It densely covered some vertical walls in the sectors 15 and 28. Collected also in a shallow shaded crevice in the harbour and in the underlayer of the rockpool with *Cystoseira* and *Sargassum*.
Polysiphonia flocculosa (C. Agardh) Endlicher		+	+	+	Common in the photophilous turfs of the lower mesolittoral and the infralittoral fringe, usually mixed with *Vertebrata fruticulosa* and articulated corallines.
Polysiphonia opaca (C. Agardh) Moris & De Notaris		+	+	+	Very common in the lower mesolittoral and in the infralittoral fringe, where it is one of the main components of the photophilous turfs.
Polysiphonia perforans Cormaci, Furnari, Pizzuto & Serio			+		Found on a thallus of *Peyssonnellia* collected in the deep infralittoral at Sciusciaù in 2017.
Polysiphonia cf. *scopulorum* Harvey			+		Epiphyte on *Peyssonnelia* at 7/8 m depth at Sciusciaù.
Polysiphonia sertularioides (Grateloup) J. Agardh		+	+	+	It forms brown patches that are clearly visible in the mesolittoral, especially in sectors 2,3 and 4.
Polysiphonia cf. *subulata* (Ducluzeau) Kützing		+	+	+	Common in the lower mesolittoral and in the infralittoral fringe, but in the form of juvenile individuals not identifiable with certainty at the species level.
Pterocladiella capillacea (S.G. Gmelin) Santelices & Hommersand			+	+	Collected in a shaded crevice in the sector 28 (with *Crouania attenuata* as epiphyte); present also in the understory of the rockpool with *Cystoseira* and *Sargassum* in the sector 10.
Pterothamnion crispum (Ducluzeau) Nägeli			+		Mixed with other filamentous algae in a collection made at 7/8 m depth at Sciusciaù in 2014.
Pterothamnion plumula (J. Ellis) Nägeli			+	+	Not frequent; some specimens observed in the sciophilous turfs collected in sectors 28–29. Epizooic on a bryozoan collected at 30 m depth in 2017.
Ptilothamnion pluma (Dillwyn) Thuret			+		Mixed with other filamentous algae in a collection made at 7/8 m depth at Sciusciaù.
Rhodophyllis divaricata (Stackhouse) Papenfuss			+	+	Common in the sciophilous turfs collected in sectors 14–15 and 28–29.
Cf. *Rhodymenia ardissonei* Feldmann	+		+		Not frequent, some specimens mixed with filamentous algae in the sciophilous turfs. Collected in shaded crevices in the harbour in 2017.
Rissoella verruculosa (A. Bertoloni) J. Agardh		+	+	+	Common in the mesolittoral but very irregularly distributed, in the form of isolated patches of variable extent (up to 1 m wide).
Rytiphlaea tinctoria (Clemente) C. Agardh			+		Found in the rockpool with *Cystoseira* and *Sargassum* in 2017.
Schottera nicaeensis (J.V. Lamouroux ex Duby) Guiry & Hollenberg			+		Found on a small vertical wall in the rockpool with *Cystoseira* e *Sargassum* in 2017.
Sphaerococcus coronopifolius Stackhouse	+				Found in shaded crevices in the harbour in 2017.
Spyridia filamentosa (Wulfen) Harvey		+	+	+	Occasionally found in the photophilous turfs of the infralittoral fringe.
Stylonema alsidii (Zanardini) Drew		+	+	+	Recorded as epiphyte on some larger algae in the infralittoral.
Stylonema cornu-cervi Reinsch		+	+	+	Recorded as epiphyte on some larger algae in the infralittoral.
Symphyocladiella parasitica (Hudson) D. Bustamante, B.Y. Won, S.C. Lindstrom & T.O. Cho			+		Found in a vacuum pump sample collected at 20 m depth at Falconara in 2014 and mixed with other infralittoral filamentous algae in 2017.
Taenioma nanum (Kützing) Papenfuss		+	+	+	Common in the photophilous turfs of the infralittoral fringe, usually associated with *Polysiphonia opaca* and *Lophosiphonia cristata*.
Tricleocarpa fragilis (Linnaeus) Huisman & R.A. Townsend			+		Collected at 7/8 m depth at Sciusciaù in 2014 and mixed with infralittoral filamentous algae in 2017.
Vertebrata fruticulosa (Wulfen) Kuntze		+	+	+	Common, widely distributed around the whole island. Mixed with other algae in the photophilic turfs of the lower mesolittoral and infralittoral fringe; noted in the upper infralittoral especially in the sectors 10–13.
Vertebrata furcellata (C. Agardh) Kuntze			+		Found in the vacuum pump samples collected at 20 m depth, both at Sciusciaù and Falconara in 2014.
Vertebrata subulifera (C. Agardh) Kuntze			+		Found in a vacuum pump sample collected at 20 m depth at Sciusciaù in 2014.
Vickersia baccata (J. Agardh) Karsakoff			+		Common in the sciophilous turfs collected in the sectors 14–15.
Womersleyella setacea (Hollenberg) R.E. Norris		+	+	+	Abundant, widely distributed at all levels of the infralittoral, both epilithic and epiphytic on other species. In the upper infralittoral is mixed with other filamentous algae in the turfs of shaded habitats.

Phylum and taxon	Sector				Distributional notes
	H	NE	SE	W	
Wrangelia penicillata (C. Agardh) C. Agardh		+	+	+	Lower mesolittoral and upper infralittoral; easily recognized by the whitish hairs present on the branches. Frequent, it is present mainly on the SE shore in sectors 10–14 and 16–17; observed also in sectors 22–24.
Wurdemannia miniata (Sprengel) Feldmann			+		Collected in 2015.
Ochrophyta					
Acinetospora crinita (Carmichael) Sauvageau			+		In 2015 it formed mucilages that covered larger infralittoral algae.
Cladostephus hirsutus (Linnaeus) Boudouresque & M. Perret-Boudouresque			+		Found in the rockpool with *Cystoseira* and *Sargassum* in 2017.
Colpomenia sinuosa (Mertens ex Roth) Derbès et Solier	+	+		+	Forming more or less extended patches in the infralittoral fringe, in the harbour and in sectors around the harbour (2–3-4–5-6, 14, 21–22–23, 28–29).
Cutleria cf. *multifida* (J.E. Smith) Greville (sporophyte *Aglaozonia*)			+		Only one plant collected at 25/30 m depth at Sciusciaù in 2014; probably common in the deep infralittoral.
Cystoseira compressa (Esper) Gerloff & Nizamuddin		+	+	+	Associated with *Ericaria amentacea*; it forms patches located immediately above those of *Ericaria amentacea* but more restricted, both horizontally and vertically. In June 2014 it was largely blackened due to drying out caused by low tides. Several large specimens occurring in the rockpool of the sector 11, together with *Sargassum vulgare* and *Gongolaria elegans*.
Dictyopteris polypodioides (A.P. De Candolle) J.V. Lamouroux	+	+	+	+	Common in a sheltered and partially shaded spot in the harbour; often observed in sheltered crevices in the upper infralittoral (where it was noticed mainly in sectors 9–17). Common in the deeper infralittoral.
Dictyota dichotoma (Hudson) J.V. Lamouroux		+	+	+	Common at all levels of the infralittoral.
Dictyota dichotoma var. *intricata* (C. Agardh) Greville		+	+	+	Abundant, one of the commonest algae in the infralittoral. In the upper infralittoral it is more common on the NE shore than on the others (where *D. fasciola*, *D. spiralis* and *T. atomaria* tend to prevail). At 10–15 m in the infralittoral is the most abundant species.
Dictyota fasciola (Roth) M.A. Howe		+	+	+	Common in the upper infralittoral, mainly on the SE shore and on the southern part of the W shore (sectors 20–24).
Dictyota implexa (Desfontaines) J.V. Lamouroux			+	+	Epiphyte on larger algae in the infralittoral; probably common.
Dictyota spiralis Montagne		+	+	+	Common in the upper infralittoral, mixed with *D. fasciola* and *Taonia atomaria*.
Ericaria amentacea (C. Agardh) Molinari & Guiry		+	+	+	Rare on the NE shore and absent in the part of the W shore closest to the harbour. Present in the form of more or less extended patches in the other parts of the coastal perimeter; on the SE shore it forms some stretches of continuous belt (usually 5–6 m long). Sectors 11–13 are those in which it appears most abundant and continuous.
Gongolaria elegans (Sauvageau) Molinari & Guiry			+		In the rockpool on the SE shore, together with *C. compressa* and *Sargassum vulgare*.
Halopteris filicina (Grateloup) Kützing		+	+	+	Common in the infralittoral and circalittoral; collected at 7/8 m depth at Sciusciaù; in the vacuum pump samples collected at 10 m depth at Falconara and at 20 depth m at Sciusciaù; epiphyte on *Lithophyllum stictiforme* in the circalittoral.
Halopteris scoparia (Linnaeus) Sauvageau	+		+		In the upper infralittoral it is present only in the harbour and in some shaded crevices in sectors 28 and 29. Abundant at deeper levels in the infralittoral zone, up to 30 m.
Nereia filiformis (J. Agardh) Zanardini			+		Some specimens epiphytic on *Peyssonnelia* at 10 m depth at Sciusciaù in 2014.
Padina pavonica (Linnaeus) Thivy		+	+	+	Common; widely distributed at all levels of the infralittoral; in the upper infralittoral noted especially in sectors 1–4, 8–14 and 27–29.
Ralfsia verrucosa (Areschoug) Areschoug		+			Not frequent, observed in the mesolittoral in the sectors 2 and 3.
Pseudolithoderma adriaticum (Hauck) Verlaque			+	+	Common in the upper infralittoral on the SE shore and in the southern part of the W shore (sectors from 7 to 23).
Sargassum vulgare C. Agardh			+		Several large specimens occurring in the rockpool of the sector 11 on the SE shore, together with *C. compressa* and *T. elegans*.
Sphacelaria cirrosa (Roth) C. Agardh		+	+	+	Common, mixed with other algae in the sciophilous turfs of the infralittoral fringe and epiphytic on many algae at deeper levels in the infralittoral. It forms small spherical aggregates around axes of articulated corallines or other algae in the shaded spots of the sectors 15–16 and 27–28.
Sphacelaria plumula Zanardini			+		Probably common in the deep infralittoral; recorded in the vacuum pump samples collected at 20 m depth at Falconara and Sciusciaù in 2014.
Sphacelaria rigidula Kützing			+	+	Recorded in the photophilous turfs of sectors 14–15 and 28–29.
Taonia atomaria (Woodward) J. Agardh		+	+	+	Abundant, very common in the upper infralittoral, especially on the SE shore; usually mixed with *Dictyota fasciola* and *D. spiralis*.

Algal assemblages of the mediolittoral zone had a patchy distribution and consisted mainly of pseudoparenchymatous red algae (*Nemalion elminthoides* (Velley) Batters, *Rissoella verruculosa* (A. Bertoloni) J. Agardh) and filamentous species (*Callithamnion granulatum* (Ducluzeau) C. Agardh, *Ceramium* spp., *Chaetomorpha* spp., *Cladophora* spp., *Polysiphonia sertularioides* (Grateloup) J. Agardh). The crustose coralline *Lithophyllum byssoides* (Lamarck) Foslie, typical of this shore level in the western Mediterranean, was found on most of the island shoreline. However, it occurred as scattered specimens up to 5 cm wide and never formed thick rims.

The composition of the algal assemblages of the infralittoral fringe (0.4/0.5 m) varied among different sectors of the shoreline, mainly in relation to morphology and inclination of the substratum. Well-developed populations of the fucalean brown algae *Ericaria amentacea* (C. Agardh) Molinari & Guiry and *Cystoseira compressa* (Esper) Gerloff & Nizamuddin occurred in some parts of the southern portion of the W shore and on the SE shore (where they occasionally formed stretches of continuous belt), whereas these species were scattered on the rest of the island. In parts of shoreline where these seaweeds were absent, the assemblages consisted of highly diverse turfs formed by articulated corallines (*Amphiroa rigida* J.V. Lamouroux, *Ellisolandia elongata* (J. Ellis & Solander) Hind & Saunders, *Jania* spp.), filamentous species (*Bryopsis* cf. *duplex*, *Falkenbergia* phase of *Asparagopsis* sp., *Ceramium* spp., *Dasya* spp., *Herposiphonia* spp., *Lophosiphonia cristata* Falkenberg, *Polysiphonia* spp., *Spyridia filamentosa* (Wulfen) Harvey, *Taenioma nanum* (Kützing) Papenfuss, *Vertebrata fruticulosa* (Wulfen) Kuntze, *Wrangelia penicillata* (C. Agardh) C. Agardh) and small-sized pseudoparenchymatous species (*Chondria boryana* (De Notaris) De Toni, *Dictyota* spp., *Gastroclonium clavatum* (Roth) Ardissone, *Gelidium* cf. *crinale* (Turner) Gaillon, *Laurencia obtusa* (Hudson) J.V. Lamouroux, *Osmundea* sp.) (Table 1). Algal turfs were also common in shaded habitats, particularly the steep cliffs of the SE shore near Punta Falconara (sectors 14–18). In these habitats, however, their composition was different: the most common species were *Acrosorium ciliolatum* (Harvey) Kylin), *Aphanocladia stichidiosa* (Funk) Ardré, *Champia parvula* (C. Agardh) Harvey, *Griffithsia phyllamphora* J. Agardh, *Herposiphonia tenella* (C. Agardh) Ambronn, *Heterosiphonia crispella* (C. Agardh) M.J. Wynne, *Hypoglossum hypoglossoides* (Stackhouse) Collins & Hervey, *Rhodophyllis divaricata* (Stackhouse) Papenfuss, *Sphacelaria* spp. and *Vickersia baccata* (J. Agardh) Karsakoff. A large upper littoral rockpool located on the SE shore (Fig. 2A; sector 10: 44°1'29.62"N, 8°13'42.97"E) hosted a distinct macroalgal assemblage, dominated by three fucalean browns (*Cystoseira compressa*, *Gongolaria elegans* (Sauvageau) Molinari & Guiry, *Sargassum vulgare* C. Agardh). During the study, some brown and red seaweeds (*Cladostephus hirsutus* (Linnaeus) Boudouresque & M. Perret-Boudouresque, *Halopithys incurva* (Hudson) Batters, *Rytiphlaea tinctoria* (Clemente) C. Agardh, *Schottera nicaeensis* (J.V. Lamouroux ex Duby) Guiry & Hollenberg) were recorded only from this rockpool, in the understory of the fucalean canopy.

The algal vegetation of the shallow infralittoral zone (up to 2/3 m depth) consisted mainly of dictyotalean brown algae (*Dictyopteris polypodioides* (A.P. De Candolle) J.V. Lamouroux, *Dictyota* spp., *Padina pavonica* (Linnaeus) Thivy, *Taonia atomaria*

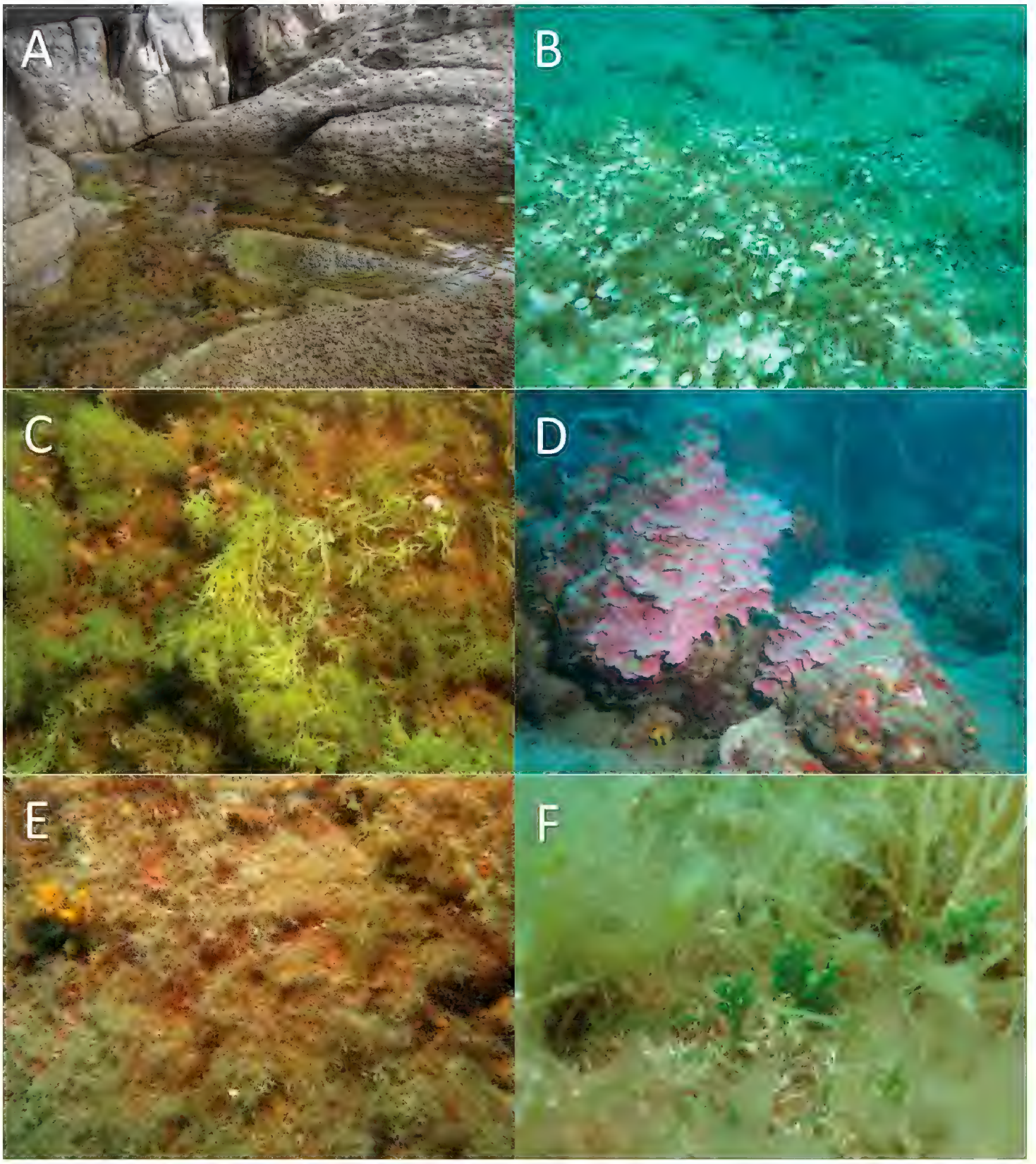

Figure 2. Details of algal communities of Gallinara Island **A** littoral rockpool on the SE shore colonized by a dense community of fucalean algae **B** a shallow infralittoral bottom at Punta Sciusciaù with a large population of *Acetabularia acetabulum* **C** a community dominated by dictyotalean brown algae (Punta Falconara, 10 m) **D** two large specimens of *Lithophyllum stictiforme* (Punta Sciusciaù, ~35 m) **E** a turf formed mostly by *Womersleyella setacea* (Punta Falconara, 30 m) **F** detail of some erect axes of *Caulerpa cylindracea* (Punta Sciusciaù, 10 m).

(Woodward) J. Agardh), patches of the articulated coralline *Ellisolandia elongata* and turfs of filamentous red algae similar to those of the infralittoral fringe. Other photophilic species typical of the north-western Mediterranean (*Acetabularia acetabulum* (Linnaeus) P.C. Silva, *Laurencia obtusa*, *Halopteris scoparia* (Linnaeus) Sauvageau) were

abundant (Fig. 2B) and thin articulated corallines (*Jania* spp.) were among the most common epiphytes. A peculiarity discovered in the shallow infralittoral zone was a population of the siphonous green alga *Pedobesia simplex* (Meneghini ex Kützing) M.J. Wynne & Leliaert formed by unattached specimens freely lying on sand in a sheltered inlet of the harbour (44°1'36.31"N, 8°13'29.56"E), at 0.5 m.

Deeper infralittoral and circalittoral zones were more heterogeneous. The parts of sea bottom towards the mainland (W-SW oriented) are characterised by a gentle slope and a patchy meadow of the seagrass *Posidonia oceanica* on sandy and coarse sediment, while toward the open sea (SE oriented) the island has steep rocky cliffs and landslide masses ending with detrital and muddy sediments at around 35 m depth, where a peculiar population of the boring sponge *Cliona viridis* (Schmidt, 1862) has been described in its gamma (massive) stage (Cerrano et al. 2007). The underwater seaward geomorphological profile at Punta Sciusciaù is characterized by vertical cliffs from the surface to 6 m depth, continuing with a plateau 20–30 m wide, with scattered rocks and pebbles with a very slight inclination down to 12 m depth, then from 12 to 24 m depth a second vertical cliff with some small terraces, followed by a gentler rocky slope from 24 m depth to 30 m depth, and then by scattered rocky blocks with coralligenous accretions. The underwater seaward profile at Punta Falconara is characterised by cliffs and landslides of boulders mixed to coarse sediments.

At the study time, exposed infralittoral rocks around 10 m depth were mainly covered by dictyotalean brown algae (Fig. 2C). Between 10 and 20 m the algal assemblages were rich and heterogeneous; they covered most of the rocky substrata and consisted mainly of *Acetabularia acetabulum*, *Codium bursa*, (Linnaeus) C. Agardh *Padina pavonica*, *Halimeda tuna* (J. Ellis & Solander) J.V. Lamouroux, *Valonia utricularis* (Roth) C. Agardh, *Bonnemaisonia asparagoides* (Woodward) C. Agardh, *Asparagopsis* sp., *Laurencia* spp., *Halopteris scoparia*, Caulerpa cylindracea Sonder, cf. Acrosymphyton purpuriferum (J. Agardh) Sjöstedt, *Ceramium* spp., *Halopteris filicina* (Grateloup) Kützing, *Tricleocarpa fragilis* (Linnaeus) Huisman & R.A. Townsend, *Peyssonnelia* spp., *Pseudochlorodesmis furcellata* and *Jania* spp. Circalittoral rocks around 30 m depth were less covered by algae. The most abundant seaweeds at these depths were *Peyssonnelia* spp., dictyotalean browns, *Lithophyllum stictiforme* (Areschoug) Hauck (Fig. 2D), *Halopteris filicina*, *Pseudochlorodesmis furcellata* (Zanardini) Børgesen, *Padina pavonica*, *Halimeda tuna*, *Valonia utricularis*, *Jania* spp. The non-indigenous filamentous red alga *Womersleyella setacea* was common both at 10 and 30 m depth, forming some nearly monospecific turfs between 20 and 30 m (Fig. 2E). The non-indigenous chlorophyte *Caulerpa cylindracea* had a similarly wide range, but it was more frequently observed at 10 m than at 30 m depth and was generally less abundant (2F).

Discussion

With 91 new records, our results increase substantially the number of macroalgal taxa for which the occurrence on Gallinara is documented. Combining our results with

information from relevant literature (Balduzzi et al. 1992; Mangialajo et al. 2004; Tunesi et al. 2006; Bianchi et al. 2018), the macroalgal flora of the island as currently known appears to consist of 162 taxa (28 Chlorophyta, 105 Rhodophyta, 29 Ochrophyta; Table S1). The number of taxa that we recorded is substantially higher than the estimate of 71 based on previous literature. Such increase is due mainly to the identification of numerous filamentous species that were not investigated in previous studies (which were based on visual census by SCUBA diving and ROV observations, methods inadequate to identify small-sized seaweeds). We believe, however, that the current estimate of 162 taxa is incomplete and probably not yet close to the actual total. Our investigations were carried out in early June, and therefore covered a limited span of the annual cycle. In the Mediterranean area early June is late spring; at this time of the year Mediterranean seaweed communities are highly species-diverse, with most species occurring in their fully developed habit. So, our sampling probably provided a good general representation of the macroalgal flora of the island. Nevertheless, it is obvious that our collections did not include seasonal species with temporal occurrence restricted to other periods (e.g., foliose red algae of the genus *Pyropia*, which in the Mediterranean occur in the mediolittoral zone in winter and early spring). In addition, our sampling could not cover the totality of benthic habitats around the island. In particular, we did not sample the meadows of *Posidonia oceanica* located in the harbour and near the northernmost part of the western shore. *Posidonia oceanica* meadows are three-dimensional environments characterized by a high associated biological diversity, with distinctive assemblages occurring on the leaves and on the rhizomes (Piazzi et al. 2002, 2015). So, almost certainly we missed some species known only or mainly as epiphytes of the leaves of this seagrass (e.g., the brown algae *Cladosiphon cylindricus* (Sauvageau) Kylin, *Giraudia sphacelarioides* Derbès & Solier, *Myriactula gracilis* van der Ben, *Myriactula rivulariae* (Suhr ex Areschoug) Feldmann and *Myrionema orbiculare* J. Agardh). We also remark that our identifications were based entirely on morphological grounds. It is now well known that this approach is insufficient to unravel the full diversity of macroalgal floras and should be integrated with DNA sequence data (Bartolo et al. 2020; Rindi et al. 2020a). This is especially true for small seaweeds with simple morphology, e.g. foliose or filamentous, which abound in the Mediterranean macroalgal flora. Cases of cryptic diversity are frequent in these algae and have been documented in the recent past (e.g., Wolf et al. 2018, 2019; Díaz-Tapia et al. 2020; Serio et al. 2020). In recent years we produced DNA sequence data from samples collected from Gallinara, as part of separate studies focusing on some species (Pezzolesi et al. 2017, 2019; Caragnano et al. 2020; Rindi et al. 2020b). One of these (Caragnano et al. 2020) unravelled a striking case of cryptic diversity: we described the new species *Lithophyllum pseudoracemus* Caragnano, Rodondi & Rindi based on samples collected from a rhodolith bed at -40 m in the area of Punta Falconara. This cryptic species was discriminated from *Lithophyllum racemus* (Lamarck) Foslie on molecular basis; probably, records of *Lithophyllum racemus* from Gallinara reported by Bianchi et al. (2018) should be referred to it. For the purpose of the present study, unfortunately, we could not generate molecular data.

Despite of these limitations, our results recovered a relatively species-diverse macroalgal flora that can be considered typical of the north-western Mediterranean. The flora of Gallinara has substantial similarities with those of north-western Mediterranean islands and coastal areas that have been floristically well investigated. Of the 162 taxa reported for Gallinara, about 110 are common to Gorgona Island (Piazzi et al. 2004), about 100 to Giannutri Island (Piazzi and Cinelli 2002) and 105–110 to the area of Calafuria, near Livorno (Rindi et al. 2002; Piazzi et al. 2009). However, the actual number of taxa common with these locations is probably higher. In our study we could not identify at species level several algae, due to the small size of the specimens or the lack of critical diagnostic features (e.g., *Bryopsis* cf. *duplex* De Notaris, *Bryopsis* sp., *Cladophora* cf. *dalmatica* Kützing, *Ulva* cf. *flexuosa* Wulfen, *Ulva* cf. *laetevirens* Areschoug, cf. *Acrosymphyton purpuriferum*, cf. *Callithamnion corymbosum* (J.E. Smith) Lyngbye, *Chondria* cf. *mairei* Feldmann-Mazoyer, *Gelidium* cf. *crinale*, *Liagora* cf. *viscida* (Forsskål) C. Agardh) (for this reason, in the floristic comparison with the abovementioned localities, we report approximate numbers). It is likely, however, that these belong to species widespread in the north-western Mediterranean.

The spatial coverage of our study does not fully correspond to previous work performed on Gallinara (Balduzzi et al. 1992; Mangialajo et al. 2004; Tunesi et al. 2006, 2008; Bianchi et al. 2018). Despite of this, our results allow some comparisons highlighting the recent changes that took place in the macroalgal communities. Our results confirm the rarefaction or loss of some large-sized brown algae, which seems to agree with the scenario of reduction of three-dimensional structure described by Bianchi et al. (2018). These authors reported a decrease of erect and canopy-forming species in parallel with an increase in filamentous algae, which caused homogenization of the epibenthic communities and destroyed the three-dimensional habitat structure that characterized Gallinara in the early 1990s. In particular, we did not record the brown seaweed *Sargassum vulgare*, either in our collections or visually, in any part of the island except the upper littoral rockpool of the SE shore. This macrophyte was common around Gallinara until 2009, when it used to form a conspicuous community in the infralittoral zone, best developed around 5 m depth (Bianchi et al. 2018). Its current rarity matches the decline described for the shores of Mediterranean France, for which habitat loss and pollution have been invoked as main causes (Thibaut et al. 2016). Similarly, we did not record two other fucalean brown algae previously reported from Gallinara, *Ericaria zosteroides* (C. Agardh) Molinari & Guiry (reported as common in the circalittoral of the SE shore by Balduzzi et al. 1992, as *Cystoseira zosteroides*; and still forming locally dense patches in the same area in July 2005, Mangialajo, personal communication) and *Gongolaria montagnei* (J. Agardh) Kuntze (reported from the W shore by Balduzzi et al. 1992, as *Cystoseira spinosa*). However, we did not investigate the deep infralittoral habitats occupied by these algae as carefully as the shallow infralittoral zone, so we may have missed them. Differently from Bianchi et al. (2018) we found that two other large brown seaweeds, *Cystoseira compressa* and *Dictyopteris polypodioides*, are still generally common on the island, although with distribution concentrated in certain habitats and certain parts of the shoreline (Table 1). These are two

widespread Mediterranean phaeophytes that thrive in a wide range of environmental conditions and may also occur at sites moderately affected by anthropogenic disturbances (Mangialajo et al. 2008; Mancuso et al. 2018; Orfanidis et al. 2021). We also confirm the presence of *Gongolaria elegans* in the rockpool on the SE shore, where this species was previously recorded by Mangialajo (2007).

However, the most remarkable difference is the widespread occurrence of the filamentous red alga *Womersleyella setacea* (Hollenberg) R.E. Norris, which was not reported in previous studies (although we suspect that the filamentous algae noted by Bianchi et al. (2018) might be mainly this species). In the 5 years of our investigation, *Womersleyella setacea* was widely distributed in the lower infralittoral and circalittoral zones, where it formed dense filamentous turfs at depths ranging between 10 and 30 m, both at Punta Sciusciaù ad Punta Falconara. The widespread presence of this alga in the north-western Mediterranean was first noted by Verlaque (1989); this author remarked its abundance in the Rade de Giens (Var, France; a bay located about 150 km from Gallinara). *Womersleyella setacea* is considered an introduction in the Mediterranean; in recent decades, dense turfs formed mostly by this species have become a feature of the seascape of several north-western Mediterranean locations (Piazzi and Cinelli 2001; Piazzi and Balata 2009; Cebrian and Rodriguez-Prieto 2012). Microscopic observation of samples from Gallinara did not reveal any reproductive structures, supporting the idea that in the Mediterranean this alga reproduces only vegetatively (as suggested by previous studies, e.g. Airoldi et al. 1995; Athanasiadis 1997; Rindi et al. 1999; Cebrian and Rodriguez-Prieto 2012). The creeping axes of this species are capable to spread quickly over the substrata occupied, covering large portions of bottom in which thick turfs develop and recruitment of seaweeds reproducing sexually or by spores is hampered (Airoldi 1998; Piazzi and Balata 2009). Ballesteros et al. (2009) suggested the development of *Womersleyella setacea* as a likely cause of the decline of *Ericaria zosteroides* (as *Cystoseira zosteroides*) in the Scandola Marine Reserve (Corsica). This scenario appears compatible with the situation observed in Gallinara. A quantitative assessment of the distribution of this species on the SE shore of Gallinara will be presented in a separate manuscript (Torsani et al., in preparation).

We also recorded two other non-indigenous species, *Caulerpa cylindracea* and *Acrothamnion preissi* (Sonder) Wollaston, known for the invasive traits that they have shown in the north-western Mediterranean. *Acrothamnion preissi* was found in very small amounts, but it might be more common than we were able to detect; this filamentous species is a common epiphyte on the rizomes of *Posidonia oceanica* (Piazzi et al. 2002). *Caulerpa cylindracea* spread aggressively in the Ligurian Sea in the last 20 years and in 2015 was reported to be still increasing its range and habitat occupancy (Montefalcone et al. 2015; Cerrano et al. 2017). Its presence on Gallinara has been known since 2005 (Tunesi et al. 2006) and Bianchi et al. (2018) reported an increase in abundance of the species in the last decade. In the course of our surveys we observed this species in the in the rockpool of the SE shore and the infralittoral zone of the SE shore where, however, it did not appear to be abundant. Future surveys will be necessary to assess whether this is indicative of a regression of *Caulerpa cylindracea* in the area or not.

Conclusions

Our results confirm that some large-sized seaweeds considered important as habitat formers have become rare or disappeared from Gallinara. Despite of this, our investigations revealed a macroalgal flora that is substantially more diverse than appreciated so far, particularly in the shallow infralittoral zone. The number of species currently documented (which, as remarked above, is certainly incomplete) is considerable for an island with a 1.4 km-long coastline. The loss or rarefaction of a few iconic species does not seem to us sufficient to conclude that the macroalgal vegetation of Gallinara must be considered impoverished. In particular, the large number of filamentous, turf-forming species, discovered should not be regarded as a reason to consider it a flora of low significance. There is a tendency to consider algal turfs as communities of lower value compared to canopy-forming species, and to treat all turfs as functionally equivalent units, regardless of their composition. In particular, most ecophysiological studies of algal turfs treat them at assemblage level and their species composition is often neglected (Provera et al. 2021). In fact, algal turfs may be very species-diverse and different turf-forming species, although morphologically similar, may respond differently to environmental change (Provera et al. 2021). So, even this component of benthic assemblages is important to study in detail in its all aspects (which has not been done for Gallinara so far).

Based on our results, we suggest that Gallinara is an interesting representative site that deserves further detailed investigation in relation to its benthic communities. In a more general perspective, considering the peculiarity of the island biodiversity, we also argue that plans for the creation of an MPA should be revitalized, in agreement with the urgent need to protect and conserve at least 30% of the Earth's lands and waters by 2030 as expected by the EU's biodiversity strategy.

Acknowledgements

We are very grateful to the staff of the Diving Club Sesto Continente (Alassio) for logistical support and assistance with fieldwork. We also thank Luisa Mangialajo (Université Côte d'Azur, Nice) for sharing useful unpublished information.

References

Airoldi L (1998) Roles of disturbance, sediment stress, and substratum retention on spatial dominance in algal turf. Ecology 79: 2759–2770. https://doi.org/10.1890/0012-9658(1998)079[2759:RODSSA]2.0.CO;2

Airoldi L, Rindi F, Cinelli F (1995) Structure, seasonal dynamics and reproductive phenology of a filamentous turf assemblage on a sediment influenced, rocky subtidal shore. Botanica Marina 38: 227–237. https://doi.org/10.1515/botm.1995.38.1-6.227

Athanasiadis A (1997) North Aegean marine algae IV. *Womersleyella setacea* (Hollenberg) R. E. Norris (Rhodophyta, Ceramiales). Botanica Marina 40: 473–476. https://doi.org/10.1515/botm.1997.40.1-6.473

Balata D, Piazzi L, Rindi F (2011) Testing a new classification of morphological functional groups of marine macroalgae for the detection of responses to stress. Marine Biology 158: 2459–2469. https://doi.org/10.1007/s00227-011-1747-y

Balduzzi A, Bianchi CN, Cattaneo-Vietti R, Cerrano C, Cocito S, Cotta S, Degl'Innocenti F, Diviacco G, Morgigni M, Morri C, Pansini M, Salvatori L, Senes L, Sgorbini S, Tunesi L (1992) Primi lineamenti di bionomia bentica dell'Isola Gallinaria (Mar Ligure). Atti Associazione Italiana di Oceanologia e Limnologia 10: 603–617.

Ballesteros E, Garrabou J, Hereu B, Zabala M, Cebrian E, Sala E (2009) Deep-water stands of *Cystoseira zosteroides* C. Agardh (Fucales, Ochrophyta) in the Northwestern Mediterranean: insights into assemblage structure and population dynamics. Estuarine Coastal and Shelf Science 82: 477–484. https://doi.org/10.1016/j.ecss.2009.02.013

Ballesteros E, Torras X, Pinedo S, Garcia M, Mangialajo L, de Torres M (2007) A new methodology based on littoral community cartography dominated by macroalgae for the implementation of the European Water Framework Directive. Marine Pollution Bulletin 55: 172–180. https://doi.org/10.1016/j.marpolbul.2006.08.038

Bartolo AG, Zammit G, Peters AF, Küpper FC (2020) The current state of DNA barcoding of macroalgae in the Mediterranean Sea: presently lacking but urgently required. Botanica Marina 63: 253–272. https://doi.org/10.1515/bot-2019-0041

Bavestrello G, Bianchi CN, Calcinai B, Cattaneo-Vietti R, Cerrano C, Morri C, Puce S, Sarà M (2000) Bio-mineralogy as a structuring factor for marine epibenthic communities. Marine Ecology Progress Series 193: 241–249. https://doi.org/10.3354/meps193241

Bianchi CN, Cocito S, Diviacco G, Dondi N, Fratangeli F, Montefalcone M, Parravicini V, Rovere A, Sgorbini S, Vacchi M, Morri C (2018) The park never born: outcome of a quarter of a century of inaction on the sea-floor integrity of a proposed but not established Marine Protected Area. Aquatic Conservation: Marine and Freshwater Ecosystems 28: 1209–1228. https://doi.org/10.1002/aqc.2918

Caragnano A, Rodondi G, Basso D, Peña V, Le Gall L, Rindi F (2020) Circumscription of *Lithophyllum racemus* (Corallinales, Rhodophyta) from the western Mediterranean Sea reveals the species *Lithophyllum pseudoracemus* sp. nov. Phycologia 59: 584–597. https://doi.org/10.1080/00318884.2020.1829348

Cebrian E, Rodriguez-Prieto C (2012) Marine invasion in the Mediterranean Sea: the role of abiotic factors when there is no biological resistance. PLoS ONE 7: e31135. https://doi.org/10.1371/journal.pone.0031135

Cecchi E, Gennaro P, Piazzi L, Ricevuto E, Serena F (2014) Development of a new biotic index for ecological status assessment of Italian coastal waters based on coralligenous macroalgal assemblages. European Journal of Phycology 49: 298–312. https://doi.org/10.1080/09670262.2014.918657

Cerrano C, Milanese M, Ponti M (2017) Diving for science – science for diving: Volunteer scuba divers support science and conservation in the Mediterranean Sea. Aquatic Conservation: Marine and Freshwater Ecosystems 27(2): 303–323. https://doi.org/10.1002/aqc.2663

Cerrano C, Sambolino P, Azzini F, Calcinai B, Bavestrello G (2007) Growth of the massive morph of *Cliona nigricans* (Schmidt 1862) (Porifera, Clionaidae) on different mineral substrata. Italian Journal of Zoology 74: 13–19. https://doi.org/10.1080/11250000600929370

Coppejans E (1983) Iconographie d'algues Méditerranées. Chlorophyta, Phaeophyta, Rhodophyta. Bibliotheca Phycologica 63: 1–28.

Cormaci M, Furnari G, Catra M, Alongi G, Giaccone G (2012) Flora marina bentonica del Mediterraneo: Phaeophyceae. Bollettino dell'Accademia Gioenia di Scienze Naturali di Catania 45: 1–508.

Cormaci M, Furnari G, Alongi G (2014) Flora marina bentonica del Mediterraneo: Chlorophyta. Bollettino dell'Accademia Gioenia di Scienze Naturali di Catania 47: 11–436.

Cormaci M, Furnari G, Alongi G (2017) Flora marina bentonica del Mediterraneo: Rhodophyta (Rhodymeniophycidae escluse). Bollettino dell'Accademia Gioenia di Scienze Naturali di Catania 50: 1–391.

Cormaci M, Furnari G, Alongi G (2020) Flora marina bentonica del Mediterraneo: Rhodophyta - Rhodymeniophycidae I. Acrosymphytales, Bonnemaisoniales, Gelidiales, Gigartinales, Gracilariales. Bollettino Accademia Gioenia di Scienze Naturali di Catania 53: 11–346. https://doi.org/10.35352/gioenia.v53i383.87

Cormaci M, Furnari G, Alongi G (2021) Flora marina bentonica del Mediterraneo: Rhodophyta - Rhodymeniophycidae II. Halymeniales, Nemastomatales, Peyssonneliales, Plocamiales, Rhodymeniales, Sebdeniales. Bollettino Accademia Gioenia di Scienze Naturali di Catania 54: 9–342. https://doi.org/10.35352/gioenia.v54i384.94

D'Archino R, Piazzi L (2021) Macroalgal assemblages as indicators of the ecological status of marine coastal systems: a review. Ecological Indicators 129: 107835. https://doi.org/10.1016/j.ecolind.2021.107835

Díaz-Tapia P, Ly M, Verbruggen H (2020) Extensive cryptic diversity in the widely distributed *Polysiphonia scopulorum* (Rhodomelaceae, Rhodophyta): molecular species delimitation and morphometric analyses. Molecular Phylogenetics and Evolution 152: 106909. https://doi.org/10.1016/j.ympev.2020.106909

Guiry MD, Guiry GM (2022) *AlgaeBase*. World-wide electronic publication, National University of Ireland, Galway. https://www.algaebase.org [searched on 25 January 2022]

Mancuso FP, Strain EMA, Piccioni E, De Clerck O, Sarà G, Airoldi L (2018) Status of vulnerable *Cystoseira* populations along the Italian infralittoral fringe, and relationships with environmental and anthropogenic variables. Marine Pollution Bulletin 129: 762–771. https://doi.org/10.1016/j.marpolbul.2017.10.068

Mangialajo L (2007) A prospection of Fucales populations in the Liguria Sea rockpools. In: Pergent-Martini C, Pergent G, Hamza A, Harmelin JG (Eds) Proceedings of the 3^{d} Mediterranean Symposium on Marine Vegetation. Regional Activity Center for Specially Protected Areas (RAC/SPA), Tunis, 282–284.

Mangialajo L, Barberis G, Cattaneo-Vietti R (2004) Contributo alla conoscenza della biodiversità macroalgale delle Aree Marine Protette Liguri. Informatore Botanico Italiano 36: 550–553.

Mangialajo L, Chiantore M, Cattaneo-Vietti R (2008) Loss of fucoid algae along a gradient of urbanisation, and structure of benthic assemblages. Marine Ecology Progress Series 358: 63–74. https://doi.org/10.3354/meps07400

Montefalcone M, Morri C, Parravicini V, Bianchi CN (2015) A tale of two invaders: divergent spreading kinetics of the alien green algae *Caulerpa taxifolia* and *Caulerpa cylindracea*. Biological Invasions 17: 2717–2728. https://doi.org/10.1007/s10530-015-0908-1

Orfanidis S, Panayotidis P, Ugland K (2011) Ecological Evaluation Index continuous formula (EEI-c) application: a step forward for functional groups, the formula and reference condition values. Mediterranean Marine Science 12: 199–232. https://doi.org/10.12681/mms.60

Orfanidis S, Rindi F, Cebrian E, Fraschetti S, Nasto I, Taskin E, Bianchelli S, Papathanasiou V, Kosmidou M, Caragnano A, Tsioli S, Ratti S, Fabbrizzi E, Verdura J, Tamburello L, Beqiraj S, Kashta L, Sota D, Papadimitriou A, Mahmoudi E, Kicaj H, Georgiadis K, Hannachi A, Danovaro R (2021) Effects of natural and anthropogenic stressors on fucalean brown seaweeds across different spatial scales in the Mediterranean Sea. Frontiers in Marine Science 8: e658417. https://doi.org/10.3389/fmars.2021.658417

Orlando-Bonaca M, Lipej L, Orfanidis S (2008) Benthic macrophytes as a tool for delineating, monitoring and assessing ecological status: the case of Slovenian coastal waters. Marine Pollution Bulletin 56: 666–676. https://doi.org/10.1016/j.marpolbul.2007.12.018

Pezzolesi L, Falace A, Kaleb S, Hernandez-Kantun JJ, Cerrano C, Rindi F (2017) Genetic and morphological variation in an ecosystem engineer, *Lithophyllum byssoides* (Corallinales, Rhodophyta). Journal of Phycology 53: 146–160. https://doi.org/10.1111/jpy.12488

Pezzolesi L, Peña V, Le Gall L, Gabrielson PW, Kaleb S, Hughey JR, Rodondi G, Hernandez-Kantun JJ, Falace A, Basso D, Cerrano C, Rindi F (2019) Mediterranean *Lithophyllum stictiforme* is a genetically diverse species complex: implications for species circumscription, biogeography and conservation of coralligenous habitats. Journal of Phycology 55: 473–492. https://doi.org/10.1111/jpy.12837

Piazzi L, Cinelli F (2001) Distribution and dominance of two introduced turf-forming macroalgae on the coast of Tuscany, Italy, northwestern Mediterranean Sea in relation to different habitats and sedimentation. Botanica Marina 44: 509–520. https://doi.org/10.1515/BOT.2001.057

Piazzi L, Cinelli F (2002) Contributo alla conoscenza dei popolamenti macroalgali dell'isola di Giannutri (Arcipelago Toscano). Informatore Botanico Italiano 34: 79–86.

Piazzi L, Balata D (2009) Invasion of alien macroalgae in different Mediterranean habitats. Biological Invasions 11: 193–204. https://doi.org/10.1007/s10530-008-9224-3

Piazzi L, Balata D, Cinelli F (2002) Epiphytic macroalgal assemblages of *Posidonia oceanica* rhizomes in the western Mediterranean. European Journal of Phycology 37: 69–76. https://doi.org/10.1017/S0967026201003432

Piazzi L, Balata D, Cinelli F (2004) Species composition and morphological groups of macroalgal assemblages around Gorgona Island (north-western Mediterranean Sea). Cryptogamie Algologie 25: 19–38.

Piazzi L, Cecchi E, Pardi G, Cinelli F (2009) I popolamenti macroalgali di Calafuria (Livorno). Atti della Società Toscana di Scienze Naturali, Memorie, Serie B 116: 81–90.

Piazzi L, Balata D, Ceccherelli G (2015) Epiphyte assemblages of the Mediterranean seagrass *Posidonia oceanica*: an overview. Marine Ecology 37: 3–41. https://doi.org/10.1111/maec.12331

Pinedo S, Garcia M, Satta MP, de Torres M, Ballesteros E (2007) Rocky-shore communities as indicators of water quality: a case study in the northwestern Mediterranean. Marine Pollution Bulletin 55: 126–135. https://doi.org/10.1016/j.marpolbul.2006.08.044

Provera I, Piñeiro-Corbeira C, Barreiro R, Diaz-Acosta L, Diaz-Tapia P (2021) Species identity matters: functional responses to warming in congeneric turfs differ from those of a canopy algae but are species-specific. Estuarine Coastal and Shelf Science 257: 107396. https://doi.org/10.1016/j.ecss.2021.107396

Regione Liguria (2020) Nuovo Atlante degli Habitat Marini sc. 1:10000. https://geoportal.regione.liguria.it/

Rindi F, Guiry MD (2004) A long-term comparison of the benthic algal flora of Clare Island, County Mayo, western Ireland. Biodiversity and Conservation 13: 471–492. https://doi.org/10.1023/B:BIOC.0000009496.32334.82

Rindi F, Guiry MD, Cinelli F (1999) Morphology and reproduction of the adventive Mediterranean rhodophyte *Polysiphonia setacea*. Hydrobiologia 398/399: 91–100. https://doi.org/10.1023/A:1017061428205

Rindi F, Pasella MM, Lee ME, Verbruggen H (2020b) Phylogeography of the Mediterranean seaweed *Halimeda tuna*. Journal of Phycology 56: 1109–1113. https://doi.org/10.1111/jpy.13006

Rindi F, Gavio B, Díaz-Tapia P, Di Camillo CG, Romagnoli T (2020a) Long-term changes in the benthic macroalgal flora of a coastal area affected by urban impacts (Conero Riviera, Mediterranean Sea). Biodiversity and Conservation 29: 2275–2295. https://doi.org/10.1007/s10531-020-01973-z

Rindi F, Sartoni G, Cinelli F (2002) A floristic account of the benthic marine algae of Tuscany (Western Mediterranean Sea). Nova Hedwigia 74: 201–250. https://doi.org/10.1127/0029-5035/2002/0074-0201

Rodríguez-Prieto C, Ballesteros E, Boisset F, Afonso-Carrillo J (2013) Guía de las macroalgas y fanerógamas marinas del Mediterráneo occidental. Ediciones Omega, S.A., Barcelona, 656 pp.

Serio D, Furnari G, Moro I, Sciuto K (2020) Molecular and morphological characterisation of *Melanothamnus testudinis* sp. nov. (Rhodophyta, Rhodomelaceae) and its distinction from *Polysiphonia carettia*. Phycologia 59: 281–291. https://doi.org/10.1080/00318884.2020.1752531

Thibaut T, Blanfuné A, Verlaque M, Boudouresque CF, Ruitton S (2016) The *Sargassum* conundrum: very rare, threatened or locally extinct in the NW Mediterranean and still lacking protection. Hydrobiologia 781: 3–23. https://doi.org/10.1007/s10750-015-2580-y

Tunesi L, Agnesi S, Di Martino V, Mo G, Molinari A, Mangialajo L, Bava S (2006) Evoluzione spazio-temporale dei popolamenti dei fondali dell'Isola Gallinaria (Mar Ligure). Biologia Marina Mediterranea 13: 104–105.

Tunesi L, Agnesi S, Di Nora T, Molinari A, Mo G (2008) Marine protected species and habitats of conservation interest in the Gallinaria Island (Ligurian Sea): a study for the establishment of the marine protected area. Atti Associazione Italiana di Oceanologia e Limnologia 19: 489–497.

Verlaque M (1989) Contribution à la flore des algues marines de Méditerranée: espéces rares ou nouvelles pour les côtes françaises. Botanica Marina 32: 101–113. https://doi.org/10.1515/botm.1989.32.2.101

Wolf MA, Buosi A, Juhmani AF, Sfriso A (2018) Shellfish import and hull fouling as vectors for new red algal introductions in the Venice Lagoon. Estuarine Coastal and Shelf Science 215: 30–38. https://doi.org/10.1016/j.ecss.2018.09.028

Wolf MA, Sciuto K, Betto VM, Moro I, Maggs CA, Sfriso A (2019) Updating *Ceramium* (Rhodophyta, Ceramiales) biodiversity in the North Adriatic Sea (Mediterranean): *Ceramium rothianum* sp. nov. and rediscovery of three forgotten species. European Journal of Phycology 54: 571–584. https://doi.org/10.1080/09670262.2019.1618919

Supplementary material 1

Table S1

Authors: Fabio Rindi, Brigitte Gavio, Laura Pezzolesi, Daniela Pica, Massimo Ponti, Fabrizio Torsani, Carlo Cerrano

Data type: docx. file

Explanation note: Summary table summarizing the macroalgal flora of Gallinara Island based on comparison of the floristic list of the present study with floristic information presented in the main literature reports.

Copyright notice: This dataset is made available under the Open Database License (http://opendatacommons.org/licenses/odbl/1.0/). The Open Database License (ODbL) is a license agreement intended to allow users to freely share, modify, and use this Dataset while maintaining this same freedom for others, provided that the original source and author(s) are credited.

Link: https://doi.org/10.3897/italianbotanist.13.81812.suppl1